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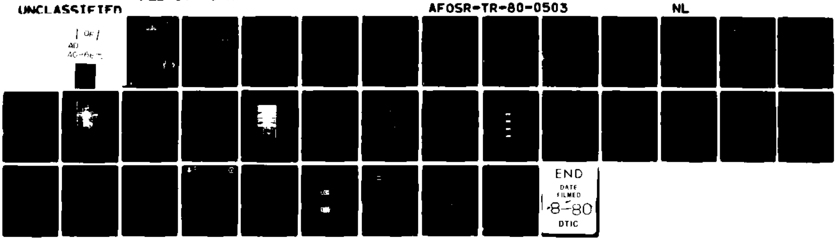

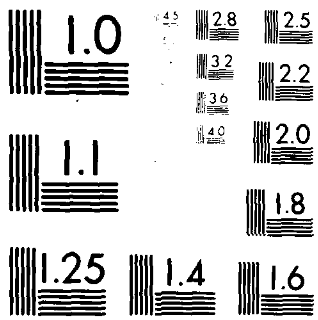

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Development of X-Ray Laser Media: Measurement of Gain and Development of Cavity Resonators for Wavelengths Near 130 Angstroms

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Laboratory for Laser Energetics
College of Engineering and Applied Science
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A new experimental facility was used to explore a range of conditions under which inverted populations on soft x-ray transitions could be produced in laser heated plasmas. Direct measurements with grating spectrographs were performed in the vicinity of 130 Å to develop the diagnostic techniques for gain determination. Designs for reflectors suitable for use in cavity resonators at soft x-ray wavelengths were developed. Construction of apparatus to produce such reflectors was begun. A patent on the reflector design was applied for.

TABLE OF CONTENTS

I. RESEARCH OBJECTIVES

In this report we describe a continuation of the development of soft x-ray laser media. This work is characterized by two primary objectives:

1. To characterize the properties of media likely to exhibit significant amplification at soft x-ray wavelengths.
2. To design and fabricate modified Langmuir-Blodgett fatty acid multilayer films to provide high reflectance (i.e. feedback) for a soft x-ray laser cavity.

In addressing the first objective we have concentrated our study on high density recombining plasmas initially heated by intense focused subnanosecond laser pulses and rapidly cooled by contact with a heat sink. We have shown experimentally that such media may exhibit a high density of inverted population at soft x-ray wavelengths under certain conditions.[1]

To address the second objective we have developed new analytic tools for the study of reflection from periodic structures containing materials with complex dielectric constants. This study has led us to new structures having multiple periodicity which can be "tuned" to arbitrary soft x-ray wavelengths. We are presently in the process of applying for a patent for these designs.

In Section II we will summarize the status of our work to date in the areas of laser plasma measurements and the design of soft x-ray reflectors.

II. SUMMARY OF WORK TO DATE

A. Laser Plasma Measurements

When very intense pulses from a laser are focused onto solid targets, a hot high density plasma is formed near the solid surface. The incident laser energy is deposited primarily near the critical density region of the plasma, i.e. the region where the plasma oscillation frequency is equal to the incident laser frequency. For a Nd^{+3}:glass laser (λ=1.054μ) the critical electron density has a value of 10^{21} cm^{-3}. Modern multistage glass laser systems producing terawatt level pulses of subnanosecond duration can achieve focused intensities exceeding 10^{16} W/cm^2 and will produce plasma electron temperatures of 1 Kev in the critical density region. Such plasmas are composed predominantly of highly stripped ions.

As the plasma expands away from the solid surface, the particle temperatures drop rapidly and recombination takes place. The two principal recombination processes occurring in the underdense region of the plasma are radiative recombination (the inverse of photoionization) and three-body recombination (the inverse of collisional ionization). It is well known that in recombining hydrogen-like and helium-like plasmas, radiative recombination favors the population of low lying principal quantum levels while three-body recombination is favored into high lying levels. Gudzenko and Shelepin first pointed out that inverted populations would be possible in recombining plasmas under conditions where three-body recombination would predominate.[7]

Numerous theoretical treatments of these conditions have subsequently been given,[2] and several reports of measured population inversions in expanding, laser produced plasmas have appeared.[3] Until recently,[1] however, none of the estimated inversion densities reported has been high enough to represent useful gain or to attempt direct demonstration of laser action.

If one compares the ratio of collisional to radiative recombination rates in hydrogen line plasmas,[4] one finds that for a given ratio of ion excited state energy to electron temperature, the electron density required for the dominance of collisional recombination scales as Z^7. Thus, provided one can excite high Z plasmas to nearly full ionized conditions, one has much higher electron densities at which inversion conditions would be favored. The corresponding population inversion densities will be higher as well. In our experiments we employed a laser of much higher power than that employed by previous workers enabling us to excite aluminum targets to the appropriate level of ionization. Previous workers were able to employ only carbon plasma. We observed population inversion at 10-1000 times higher electron density than previously observed.

One problem which develops at high particle densities is that collisional recombination may occur very rapidly, before the plasma has had time to expand, cool, and insure depopulation of the lower lying states. To provide for adequate cooling in our experiments a stepped target design was employed to provide a high density heat sink in the expanding plasma.

Our experimental arrangement is shown in Figure 1. A multistage mode-locked Nd^{+3}:glass laser was employed producing single 200 psec pulses with up to 10J in energy. The laser pulses were focused on the aluminum target surface by an f/3.5 aspheric lens so that the edge of the focused beam grazed a thin magnesium plate set slightly in front of the aluminum block. A spatially resolving crystal spectrograph was located near the target surface and oriented to record the radiation from the expanding plasma. The spatial dispersion was arranged along the directional normal to the target surface. The spectrograph recorded emission lines from the plasma in the wavelength range of 6 - 8Å, corresponding to radiative transitions from the various principal quantum levels of Al^{+11} and Al^{+12} to the respective ground states. In the underdense regions of the expanding plasma, collisional depopulation of the excited states is negligible compared to radiative decay. Thus the intensities of the emission lines are a direct measure of the level populations.

In Figure 2, two spectra obtained from the instrument described above are shown. These spectra were recorded on the same single shot but were produced by emitting regions at different distances from the target surface. The upper trace shows the emission spectrum near the target surface. The regular decrease in the line intensities as a function of principal quantum number in the two ion species is normal for high density high temperature plasmas. In the lower spectrum, recorded from a region approximately 400 μm from the target surface, a distinct reversal of this trend is evident in the helium-like series, An unambiguous inversion in emission intensity, and thus in population, between the 1s4p and 1s3p levels is evident. A complete examination of

EXPERIMENTAL CONFIGURATION FOR MEASURING POPULATION INVERSION

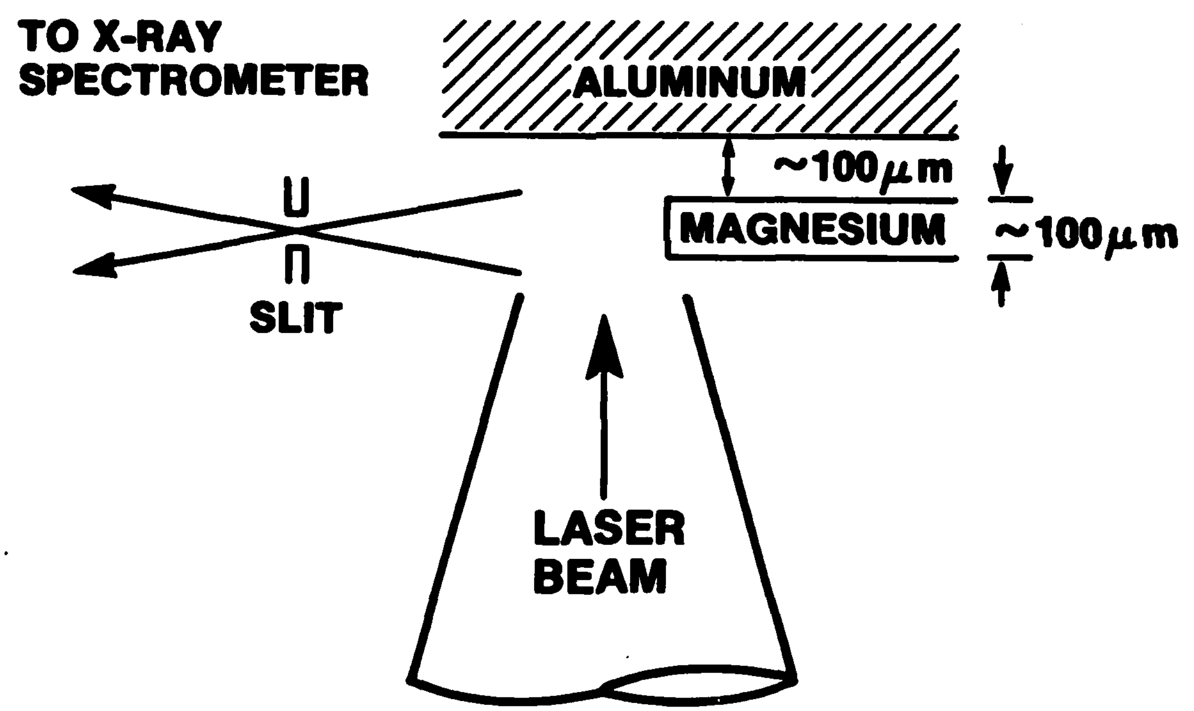


Figure 1

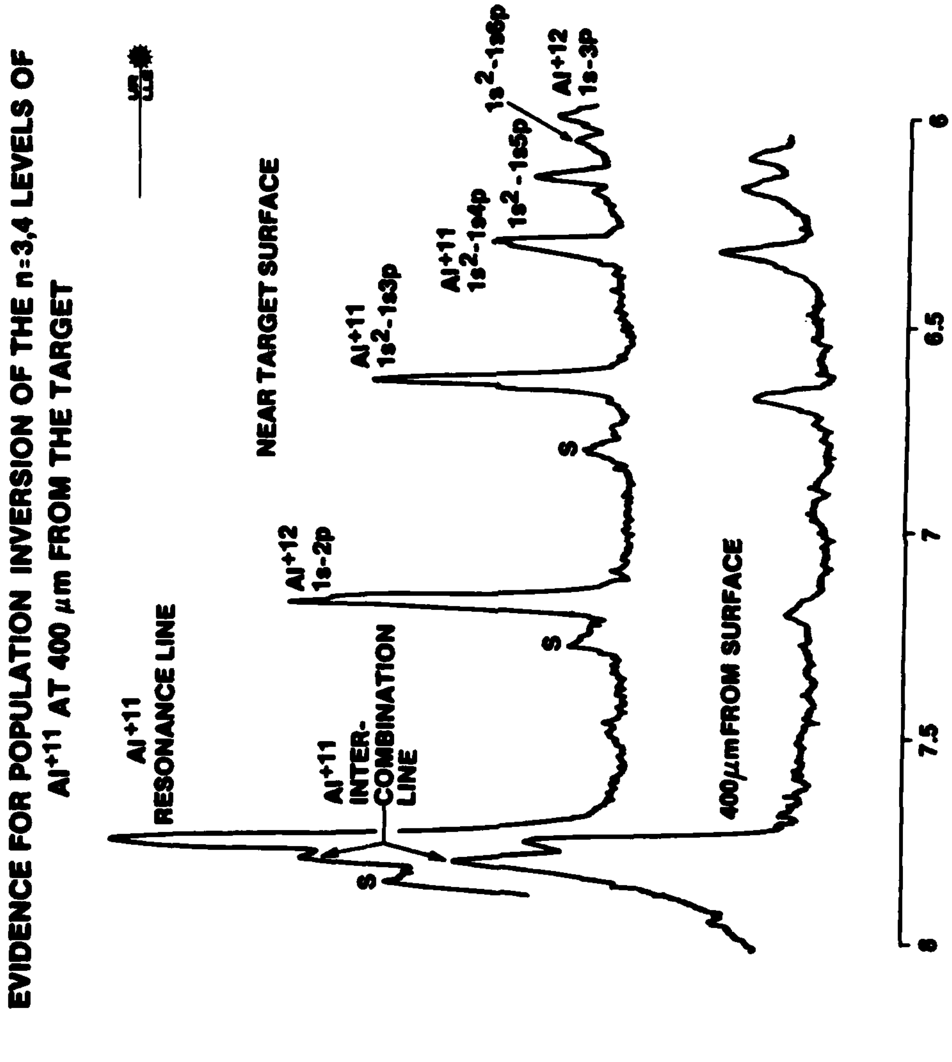

EVIDENCE FOR POPULATION INVERSION OF THE n=3,4 LEVELS OF Al^{+11} AT 400 μm FROM THE TARGET
NEAR TARGET SURFACE
Al^{+11} RESONANCE LINE
Al^{+11} INTER-COMBINATION LINE
S
Al^{+12} 1s-2p
S
Al^{+11} $1s^2$-1s3p
Al^{+11} $1s^2$-1s4p
$1s^2$-1s5p
$1s^2$-1s6p
Al^{+12} 1s-3p
400 μm FROM SURFACE
8
7.5
7
6.5
6
WAVELENGTH (Å)

Figure 2

such spectra shows that in the geometry employed here, population inversion between these levels begins approximately 150 μm from the target surface, reaching its maximum density approximately 350 μm from the surface.

Since our initial measurements, described above, were made our experimental apparatus was moved into the new Laboratory for Laser Energetics (LLE) facility and installed in a laboratory located to receive pulses produced by LLE's Glass Development Laser (GDL). This laser was built as an engineering prototype of the 24 beam OMEGA laser system currently under construction at LLE. The prototype studies were completed in 1978 and the GDL system is now being used to perform a variety of scientific experiments, including the soft x-ray laser development experiments to be described. The GDL system is rated at 500 GW pulse power in 50 psec FWHM pulses and up to 160 joules per pulse in 1 nsec FWHM pulses. The pulse repetition rate is 2 shots per hour, the highest of any high power glass laser system in operation or under construction. A beam divergence of 100 μrad or better is measured at full rated output. This corresponds to near diffraction limited performance at the output aperture of 9 cm and is achieved by extensive use of spatial filters in the laser amplifier chain. A schematic diagram of the GDL system is given in Figure 3.

The GDL system is equipped with two mode-locked oscillators, one optimized for short pulse (e.g. 50 psec) production and the other optimized for long pulse (e.g. 500 psec) production. This enables rapid changeover in system pulsewidth to efficiently fill the requirement of the several experimental facilities served by the GDL laser system.

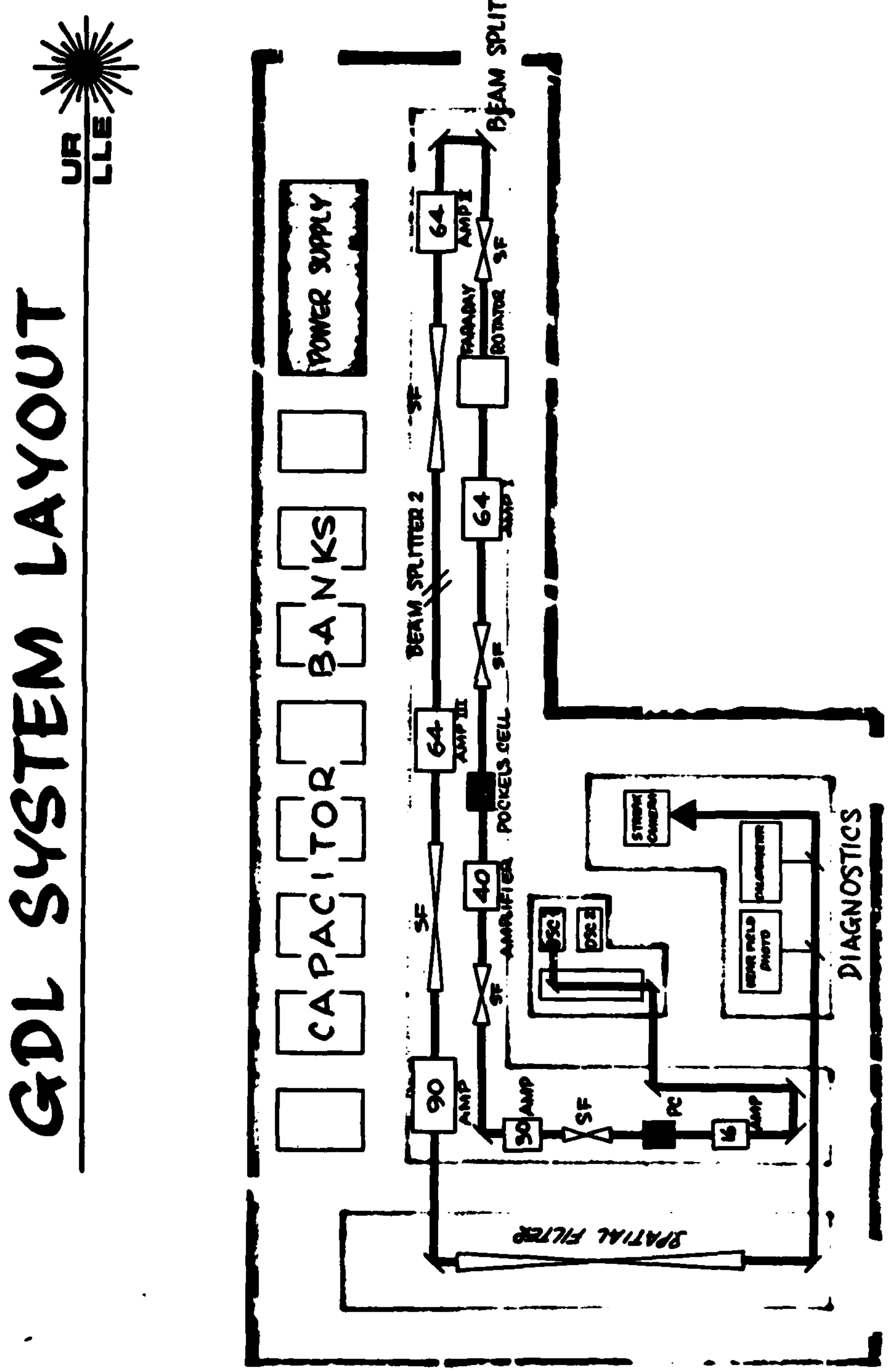

GDL SYSTEM LAYOUT
UR
LLE
CAPACITOR
BANKS
POWER SUPPLY
BEAM SPLITTER 1
BEAM SPLITTER 2
FARADAY
ROTATOR
64
AMP I
AMP II
AMP III
SF
POCKELS CELL
40
AMPLIFIER
90
AMP
30
PC
16
DIAGNOSTICS
SPATIAL FILTER

Figure 3

The spatially resolved crystal spectrograph experiments described above were repeated using the GDL laser system at 150 psec, 400 psec, and 700 psec FWHM pulses. The results obtained are quite similar to that shown in Figure 2 and show little dependence on laser pulsewidth. This suggests that the plasma expansion from the solid surface may be characterized by a kind of stationary flow in this geometry and that the heat sink has more than a transient effect on the temperature profile in the expansion region. Further experiments were conducted to determine the characteristics of the heat sink.

To learn more about the transport of energy from the plasma to the heat sink the geometry shown in Figure 1 was modified by adding a second heat sink element in the plane of the first, but with its edge on the other side of the core of focused rays from the laser pulse. This results in a heat sink geometry in the form of a slit. The orientation of the heat sink slit was chosen to allow the spatially resolving crystal spectrograph to view along the slit opening, perpendicular to the view illustrated in Figure 1.

A spatially resolved spectrogram is shown in Figure 4 which illustrates both the experimental technique and the operation of the heat sink. In this experiment a 58 joule 400 psec FWHM laser pulse was focused on the surface of an aluminum target to a focal spot diameter of approximately 100 μm. The heat sink slit was constructed of lead foil and was located 100 μm from the target surface and had an opening of approximately 200 μm. The spectrograph slit was oriented with its opening in the plane of incidence of the flat diffracting crystal providing spatial resolution normal to the surface of the target. The slit was adjusted to give a spatial resolution of approximately 50 μm.

When the spectral components of the source are well separated in the spectrograph, as is the case here, the observed widths of the lines will be determined by the spatial extent of the source unless a second slit is included in the spectrograph with its opening normal to the plane of diffraction. We deliberately omit the second slit in order to obtain spatial resolution of the source parallel to the surface of the target, in this case of the order of 40 μm. In effect, then, we have two dimensional spatial resolution of the emission of each of the principal emission lines from aluminum ions in the range of 5 - 8Å.

The spatial resolution slit is constructed out of two small steel pins which allow some radiation to pass directly to the crystal on either side of the pins. The spectra recorded here are spatially integrated in the direction normal to the target. The spatial integration is complete outside the shadow of the pins. However, the shadow of the pin farthest from the target surface will be partially illuminated by radiation from the expanding plasma. This shadowgram spectrum is partially spatially integrated and is increasingly localized into the shadow.

In Figure 4 we see fully integrated spectra displayed vertically on the right- and left-hand side of the figure. The shadowgram spectrum is visible in the left-hand shadow which the fully spatially resolved spectrum appears in the center. In this geometry the image magnification varies slightly along the direction of spectral dispersion so a spatial scale has been included on the left side of the figure. Identification of the hydrogen-like (Lyman) transitions and of the upper levels corresponding to transitions to the ground state in the helium-

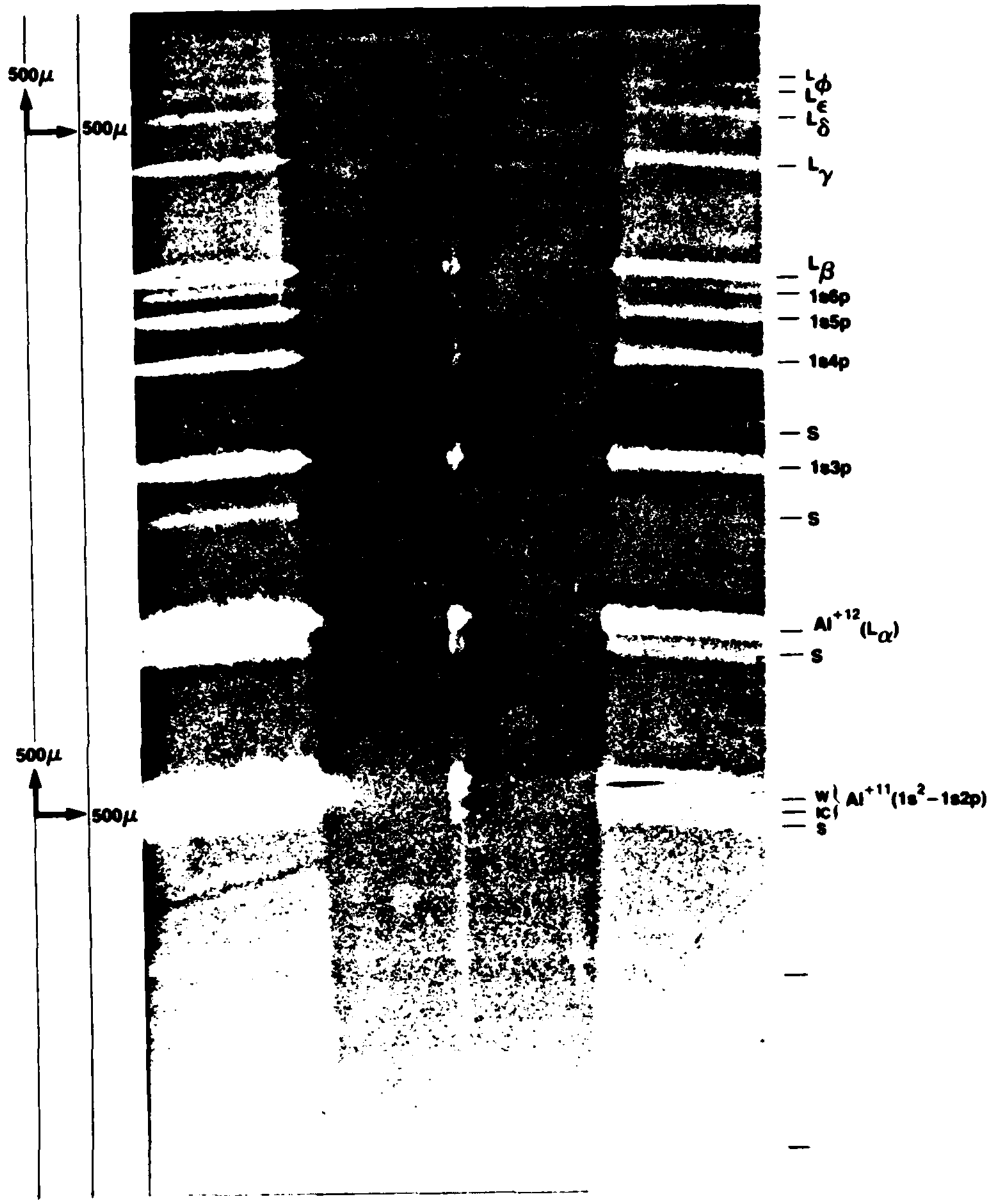

500μ
500μ
500μ
500μ
Lφ
Lε
Lδ
Lγ
Lβ
1s6p
1s5p
1s4p
S
1s3p
S
Al+12 (Lα)
S
W
IC
S
Al+11 (1s2−1s2p)
shot #960
58.1 Joules—400 psec
target: Al+Pb (slit)
X140

Figure 4

like ions of aluminum is given on the right hand side of the figure. The target surface position in the spatially resolved spectra is at the left side portion of each spectrum with the plasma expanding toward the right.

Several interesting features are apparent in the spatially resolved spectrum in Figure 4. Each line in the spectrum exhibits bright emission near the target surface, the hot, high density region of the plasma. The emission drops abruptly due to the gradual decrease in both temperature and density in the expanding plasma until it strikes the heat sink. At this point the emission increases dramatically, particularly in the higher series lines from the helium-like ions where the emission becomes brighter than it was at the target surface. This is consistent with an enhanced degree of collisional recombination, due to a sudden local temperature drop, which favors population of the higher quantum levels of an atom. It appears that the instantaneous effect of the heat sink is quite localized and is produced by collision of plasma ions with the heat sink surface, rather than due to a pre-plasma produced from the heat sink by the edges of the laser beam. As the aluminum plasma expands beyond the heat sink, lateral thermal conduction cools the central portion of the jet and the emission lines persist for several hundred microns or more, particularly from the higher lying series members. (This persistence is better exhibited on the microdensitometer traces in Figure 2 than in the spectrogram reproduction in Figure 4.)

With this spatially resolved spectroscopic technique we may now begin to address the question of the optimization of the heat sink construction. The results of an experiment to test the effect of heat sink composition is shown in Figure 5. The target irradiation conditions were similar to those used to obtain Figure 4 except that the heat sink was composed of two different metals. With reference to the figure the upper edge of the heat sink was made of a magnesium foil which the lower edge was made of lead foil. With reference to the emission in the plane of the heat sink there is no clear difference in the effectiveness of the two materials even though they have quite different thermal conductivities and heat capacities.

It is interesting to observe the appearance of magnesium lines in this spectrum. The emission begins at the heat sink surface and moves outward, away from the target surface. This is consistent with collisional heating and momentum transfer from the expanding aluminum plasma. If the heat sink were being ionized by the edge of the laser pulse one might expect some motion of the magnesium ions toward the target surface as well.

Since the observation of inverted populations appears to be straightforward with our technique, and since it does not appear to critically depend upon the various experimental parameters, we have now turned our attention to direct measurements of the emission from the various excited state transitions of helium-like aluminum in the range from 50 to 400 Å. These measurements are being made with a grazing incidence grating spectrograph.

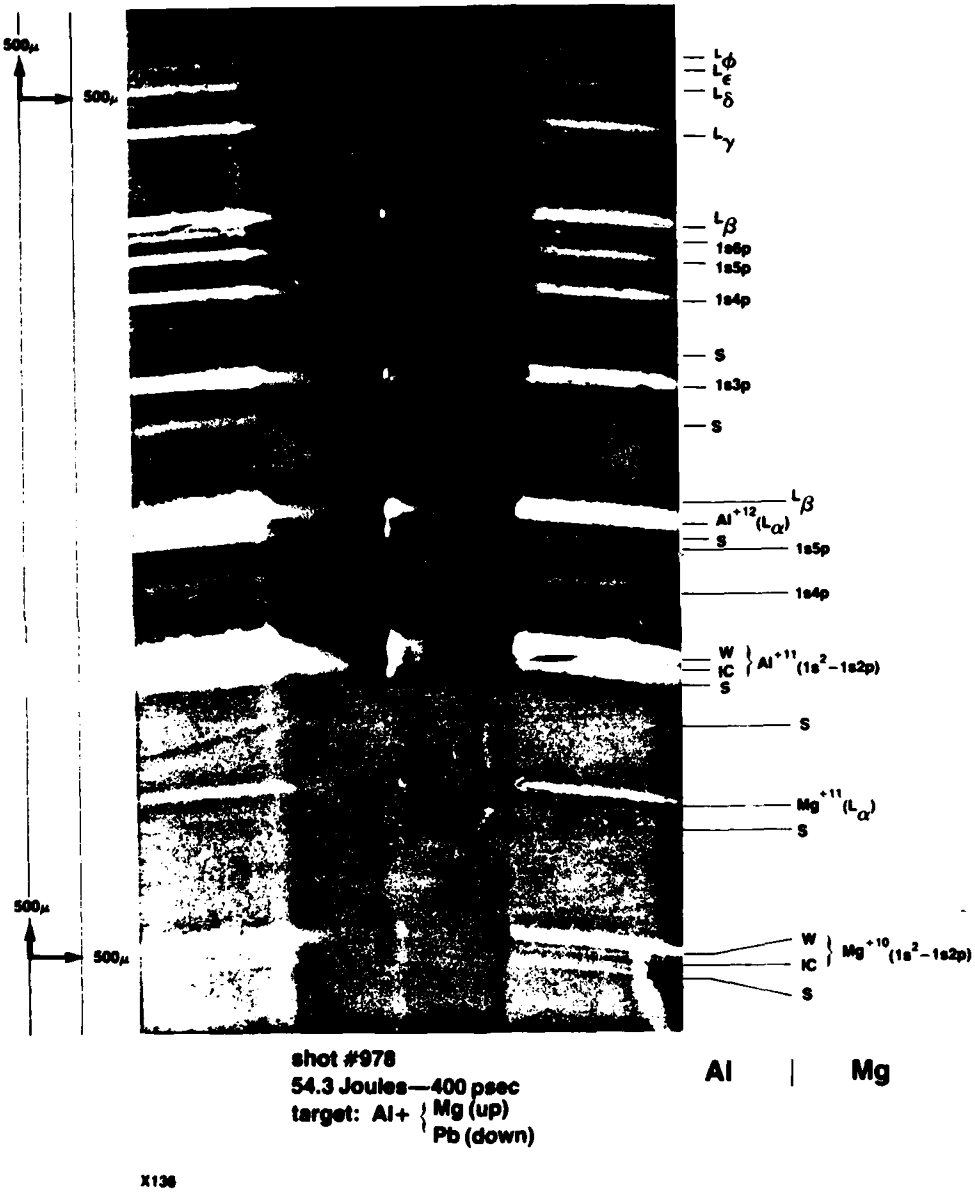

500μ
500μ
Lφ
Lε
Lδ
Lγ
Lβ
1s6p
1s5p
1s4p
S
1s3p
S
Lβ
Al+12 (Lα)
S
1s5p
1s4p
W
IC
Al+11 (1s²−1s2p)
S
S
Mg+11 (Lα)
S
500μ
500μ
W
IC
Mg+10 (1s²−1s2p)
S
shot #978
54.3 Joules—400 psec
target: Al+ { Mg (up) / Pb (down)
Al | Mg
X136

Figure 5

Our first tests with this spectrograph have just been completed at this writing. Our spectrograph was fitted with a 40 cm radius, 600 grove/mm platinum coated grating with a blaze angle of 1^{o} 35'. The entrance slit was 20 μm wide for these first tests and located approximately 10 cm from the laser plasma. The spectrograph was fitted with a spatially resolving slit approximately 100 μm wide; the spectrograph viewing direction was along the target surface so the emission was spatially resolved in the direction of plasma expansion.

A microdensitometer trace of one portion of a grating spectrum is shown in Figure 6. This recording was obtained from a single 87.7 joule 700 psec FWHM laser pulse. The wavelength scale is only approximate and we are just beginning the task of identifying the prominent spectral components in the recording. At this juncture the important point is that we have demonstrated single shot recording capability in this spectral region and are prepared to begin a systematic investigation to discover radiation transport effects in line focus geometry associated with an amplifying condition.[5]

B. Reflecting Structures for Soft X-Ray Cavity Resonators

We describe a mirror structure that can provide a high normal incidence reflectivity at any chosen soft x-ray wavelength in the range 70Å - 300Å, where conventional metallic reflectors cannot function. The new reflector is a modified multiple bilayer structure consisting of a periodic array of fatty acid films separated by thin metallic layers. Schematic enlargements of typical structures are shown in Figures 7 and 8.

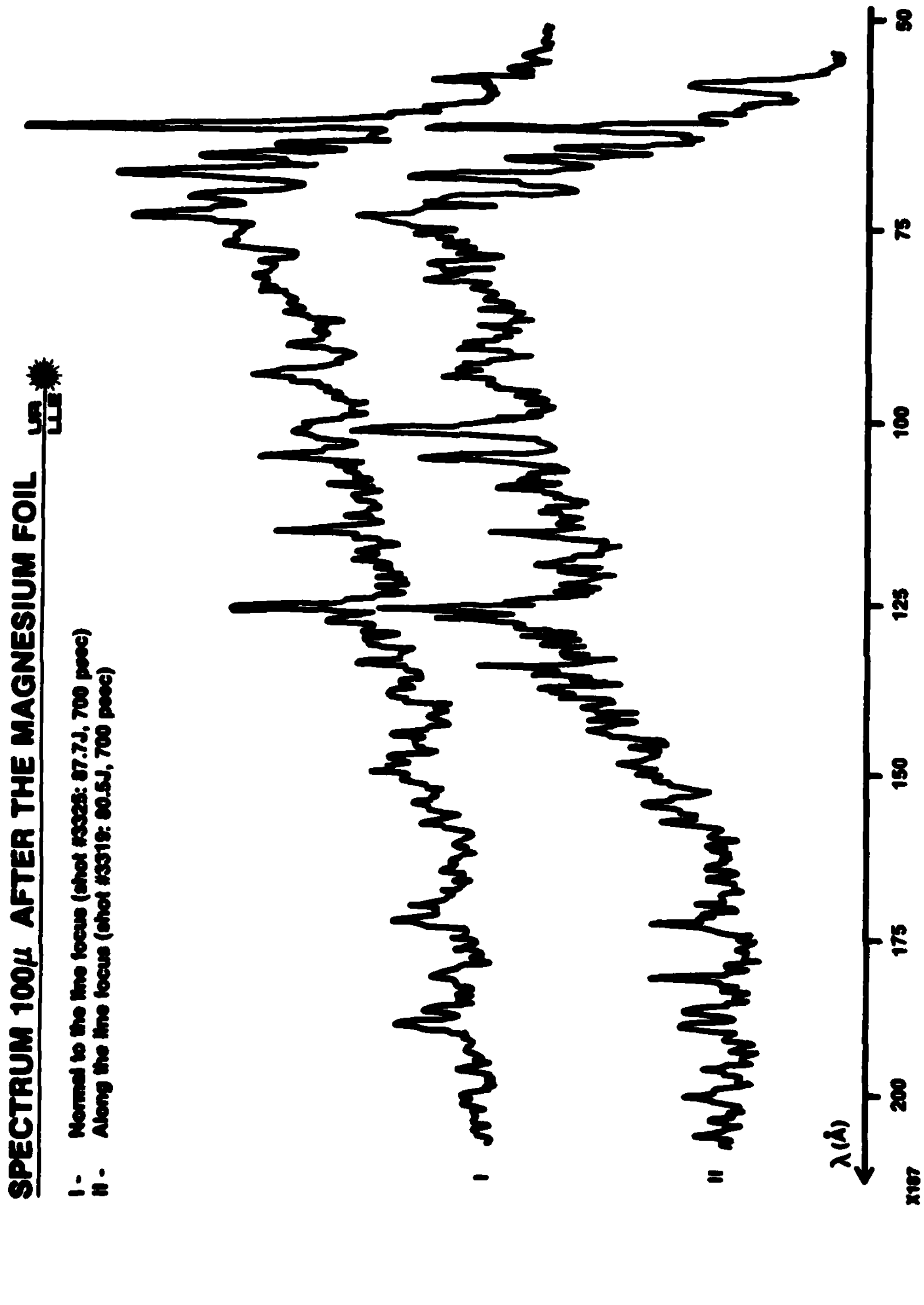

SPECTRUM 100μ AFTER THE MAGNESIUM FOIL
UR LLE
I - Normal to the line focus (shot #3325: 87.7J, 700 psec)
II - Along the line focus (shot #3319: 90.5J, 700 psec)
I
II
50
75
100
125
150
175
200
λ(Å)
X187

Figure 6

USE OF MIXED SPACINGS TO MATCH MIRROR RESONANCE TO SOURCE WAVELENGTH

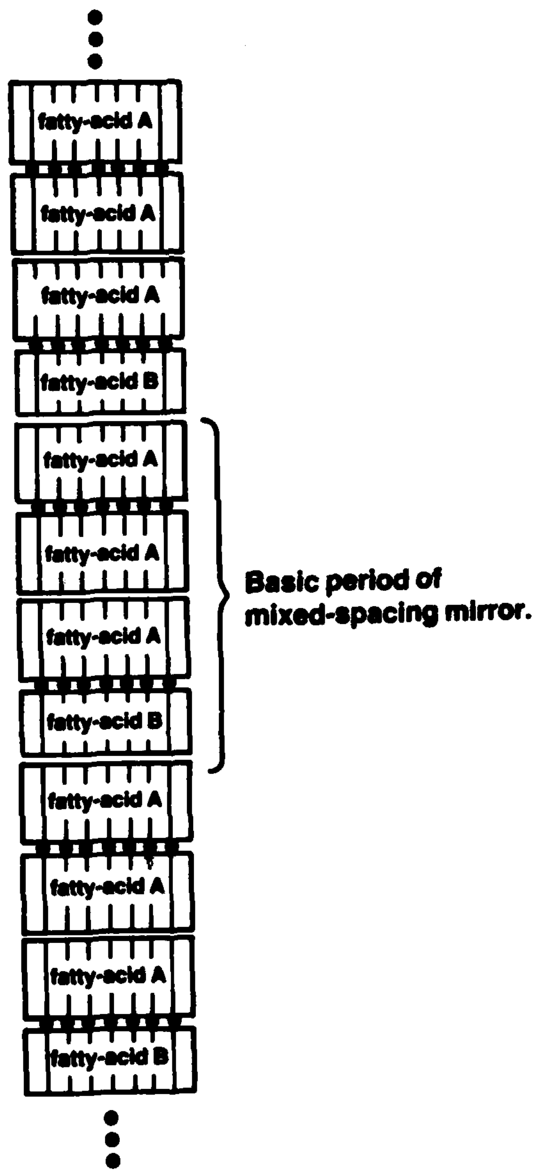
In this example:

$N_A = 3N_B$

Then:

$\lambda_{PEAK} \cong \frac{3}{4}2d_A + \frac{1}{4}2d_B$

(for $2d_A - 2d_B$ small)



X178

Figure 7

A HYBRID MULTILAYER CONTAINING LANGMUIR-BLODGETT AND VACUUM DEPOSITED LAYERS

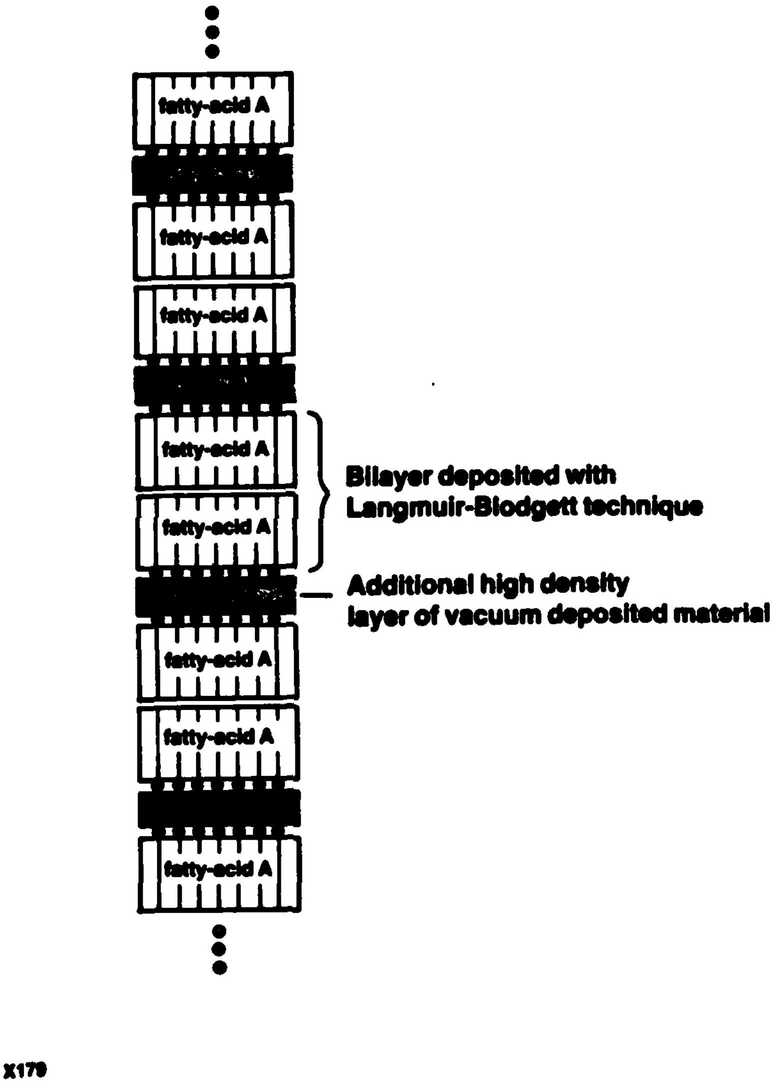


Figure 8

Principles of Operation

At wavelengths shorter than 300Å, ordinary disordered solid materials have very weak normal incidence reflectances since their indices of refraction approach closely to unity. Similarly, a weak reflection may be obtained at each boundary in a periodic structure of the sort formed when layers of high and low density material are deposited alternately. If the period length of the structure is set to the correct value, which will be near but not precisely equal to half the wavelength of the normally incident radiation, the reflected components from the various boundaries will combine constructively to yield a strong overall reflection.

A well-known class of structures that satisfy the above conditions at certain wavelengths in the range 70Å - 160Å are the Langmuir-Blodgett multilayers. Such a structure is formed by floating a monomolecular fatty acid film on a heavy metal ion solution and then attaching the monolayer to a mirror substrate by dipping the substrate into the solution (Figure 9). A layer is deposited on each downstroke and sometimes on each upstroke, and the bilayer molecular alignment shown in Figure 10 is obtained. A multiple bilayer structure is then formed as the dipping of the substrate into the aqueous suspension is repeated.[6] These structures can provide significant normal incidence reflection only at a set of discretely spaced soft x-ray wavelengths corresponding to the discrete set of fatty acid molecular chain lengths. Furthermore, the low concentration of heavy ions in the metallic salts of fatty acids implies that a large number of layers must be used to achieve good reflectivity.

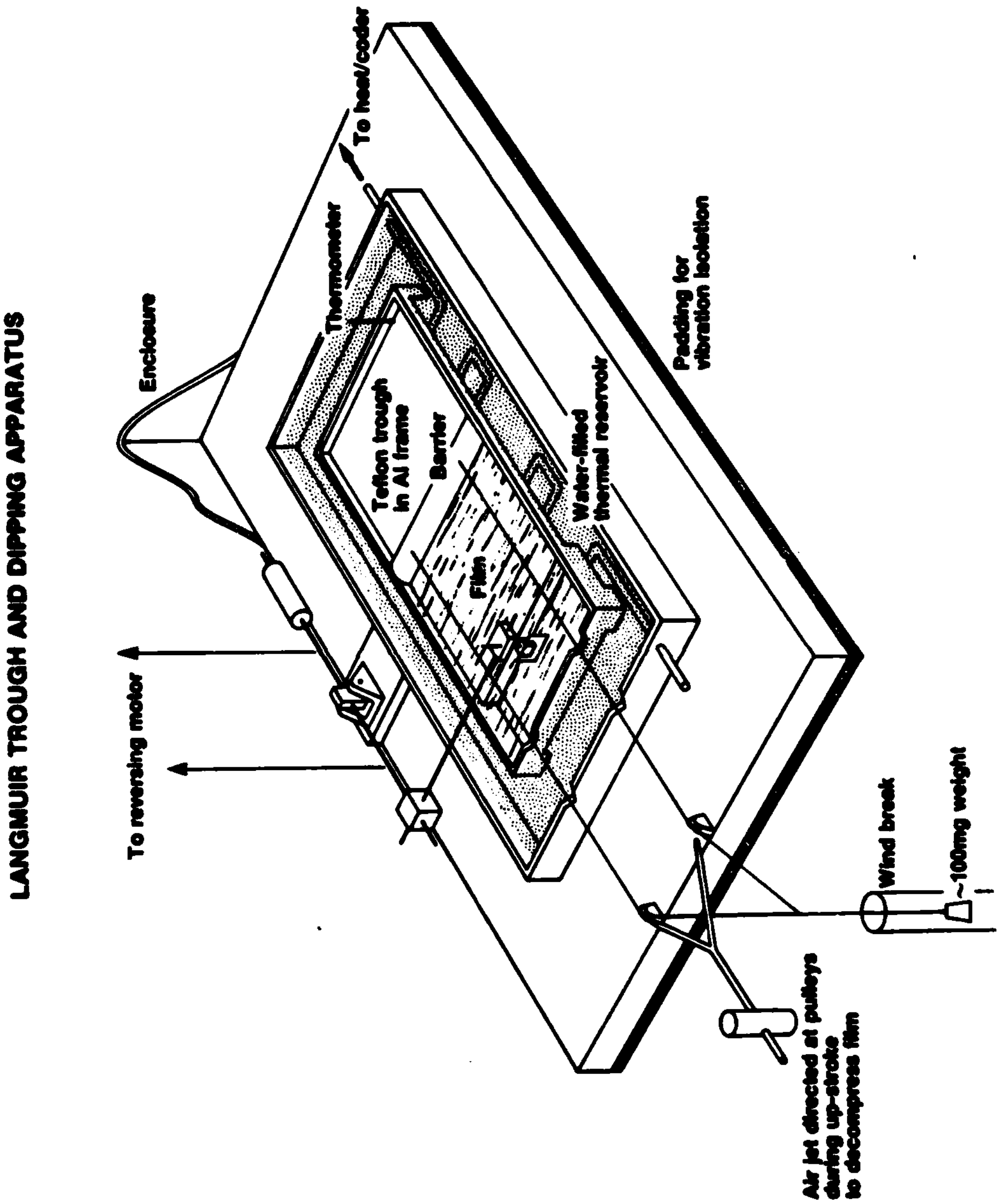

LANGMUIR TROUGH AND DIPPING APPARATUS
Enclosure
To reversing motor
Thermometer
To heat/cooler
Teflon trough
in Al frame
Barrier
Film
Water-filled
thermal reservoir
Padding for
vibration isolation
Wind break
~100mg weight
Air jet directed at pulleys
during up-stroke
to decompress film

Figure 9

Caption to Figure 9

The pool of water that supports the film is contained in a Teflon-coated Al trough. The water is doubly distilled, and can be cooled or heated relative to the surrounding environment.

The film is compressed by a force supplied to a moveable barrier through weights. The barrier is made of sheet Teflon and "floats" on the water surface. It is slightly wider than the trough but is not in contact with the trough edge; instead it rides on a thin layer of water pinched between the trough edge and itself.

The seesaw-like device that dips the substrate into the film is powered by a reversing motor (not shown; the motor is mounted on a separate table for vibration isolation).

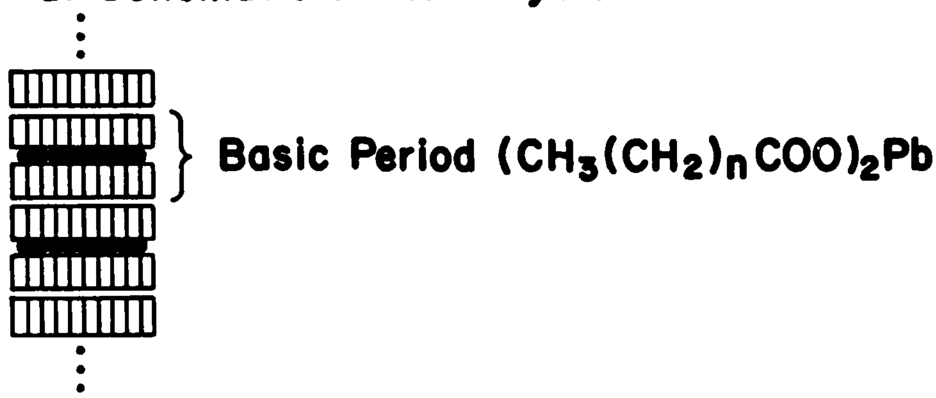
Deposition occurs primarily on the down-strokes, but poor quality up-stroke depositions can take place during the first few cycles. To inhibit these, a jet of air is directed at the pulleys during the up-strokes in order to decompress the film.

The Teflon trough and aluminum supporting frame rest in a water-filled thermal reservoir cooled or heated by a NESLAB RTE-3 circulator.

The apparatus is surrounded by a plexiglass enclosure with optional nitrogen-purging, and is mounted on a layer of padding for vibration-isolation. The Teflon parts are cleaned with chromic acid between fabrication sessions.

Langmuir-Blodgett Multilayer

a. Schematic of multilayer.



b. Schematic of basic period.

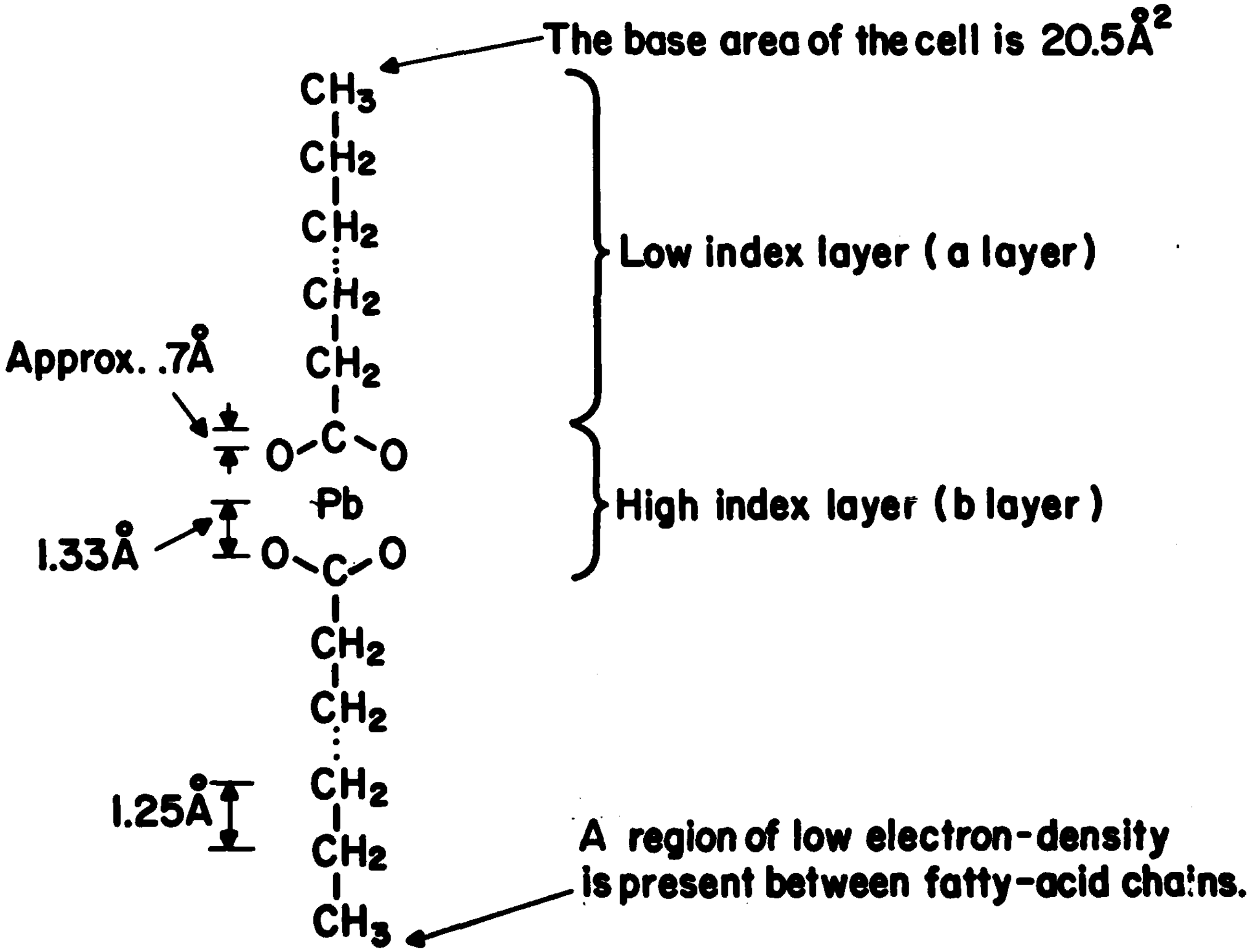


Figure 10

This increase in the number of required layers causes an accompanying increase in absorption, reducing the reflectivity finally obtained.

In the structure described in Figure 7, the wavelength of peak reflectivity has been shifted away from any of the discrete values that a mirror made from a single fatty acid molecule would be restricted to; this has been accomplished by periodically inserting into the structure layers formed from a second species of fatty acid. Increased spacings between the metallic layers can be obtained by transferring some of the fatty acid films from an aqueous substrate not containing metallic ions. The effective period thickness of the structure then becomes approximately the arithmetic mean of all spacing distances in the structure's physical repeat period. Since good performance is obtained from such structures over a small but finite range of wavelengths, a limited set of molecular combinations can provide high reflectance over all wavelengths in the 70Å - 300Å range. (The upper limit simply represents the approximate short wavelength cutoff of conventional reflectors.)

The reflectance of such structures is further enhanced if an additional thin metallic layer is deposited on each monatomic metallic layer that is deposited with the Langmuir-Blodgett technique (Figure 8). This increases the interaction of each individual period with the x-rays, allowing the use of fewer periods in the mirror and consequently the production of mirrors having reduced absorption. If additional metallic layers are used, the resonant wavelength of the mirror can be controlled through variation of the thickness of these layers, rather than through the use of fatty acids having non-uniform molecular lengths.

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APPENDIX I

Summaries of papers presented at the Annual Meeting of the Optical Society of America, October 8-12, 1979, Rochester, New York.

EUV AND X-RAY SPECTROSCOPY OF AN INVERTED LASER-PRODUCED ALUMINUM PLASMA*

Yves Conturie and J. M. Forsyth

An aluminum plasma produced by a point-focus Nd^{3+}-Glass laser (500 psec, up to 100 J) is cooled at an early stage of its expansion by a "heat sink," a metallic foil placed near the surface of the Al target.[1] High electron density and low temperature increase the probability of recombination through three-body rather than radiative processes, favoring the population of high-lying quantum states.[2] Two spatially resolving crystal-spectrographs at perpendicular directions provide three-dimensional information on the transitions to the ground-state in the H-like and He-like stages of the plasma. Two target geometries show evidence of population inversion between several Al^{+11} levels and possibly between the n=4 and 3 Al^{+12} levels:
(i) a magnesium slit in front of an aluminum slab at normal incidence,
(ii) a magnesium sheet on the side of a tilted aluminum slab. A grazing-incidence grating spectrograph is used for direct observation of the inverted transitions. Single-shot Al spectra in the range 50 Å - 500 Å are presented. Single-shot Fe spectra recorded under the same conditions provide a reference for the line identification. Preliminary results on line-focus experiments (using a cylindrical lens) are also presented.

*Research Supported, in part, by AFOSR Grant 77-3189.

[1]Bhagavatula and Yaakobi, Opt. Comm. 24, 331 (1978).

[2]McWhirter and Hearm, Proc. Phys. Soc. 82, 641 (1963).

NORMAL INCIDENCE SOFT X-RAY REFLECTORS FOR ARBITRARY WAVELENGTHS USING A MODIFIED LANGMUIR BLODGETT METHOD*

Alan E. Rosenbluth and J. M. Forsyth

X-ray reflectors operating near normal incidence must contain a large number of (near) quarter-wave periods due to the weak interaction of x-rays with matter. As a result, the production of such reflectors using conventional layer deposition techniques presents a challenging problem.[1]

For wavelengths in the 100 Å regime, the stringent tolerances involved can be met using the Langmuir-Blodgett technique, in which successive portions of a monomolecular fatty-acid film are transferred from an aqueous to a solid substrate.[2]

The technique may be modified in an effort to produce mirrors tuned to reflect arbitrary source wavelengths. One such modification makes use of mirrors in which different layers are formed from different molecules; another uses mirrors in which the high-index layers formed by the head-groups of the molecules are augmented.

An equivalent-index analysis of such structures indicates that reflectors of the first type have an absorption-limited performance of about 10%; reflectivities of roughly 50% appear to be possible in principle from reflectors of the second type.

Such reflectors might serve as cavity mirrors in an x-ray laser. The technology involved may also be useful in surface-smoothing, and in x-ray astronomy, microscopy, and lithography.

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[1]R.P. Haelbich, A. Segmüller, and E. Spiller, Appl. Phys. Lett., 34 (3), 1979, p. 184.

[2]G.L. Gaines, Jr., Insoluble Monolayers at Liquid-Gas Interfaces, Interscience, 1966.

High Reflectance Normal Incidence Mirrors for Arbitrary Soft X-Ray Wavelengths between 70-300Å

Illustrations: Figures 1, 2, and 3 are attached.

Description

We describe a mirror structure that can provide a high normal incidence reflectivity at any chosen soft x-ray wavelength in the range 70Å-300Å, where conventional metallic reflectors cannot function. The new reflector is a modified multiple bilayer structure consisting of a periodic array of fatty acid films separated by thin metallic layers.

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Publications

Alan E. Rosenbluth, "Normal Incidence Reflectors for Soft X-Rays," Institute of Optics, Spring, 1979, Industrial Associates Meeting, Rochester NY, April 25, 1979.

Alan E. Rosenbluth, J. M. Forsyth, "Normal Incidence Soft X-Ray Reflectors for Arbitrary Wavelengths Using a Modified Langmuir-Blodgett Method," Optical Society of America, 1979 Annual Meeting, Rochetser NY, Oct. 10, 1979.

A well-known class of periodic structures that satisfy resonant reflectance conditions at certain wavelengths in the range 70Å-160Å are the Langmuir-Blodgett multilayers. Such a structure is formed by floating a monomolecular fatty acid film on a heavy metal ion solution and then attaching the monolayer to a mirror substrate by dipping the substrate into the solution. A layer is deposited on each downstroke and sometimes on each upstroke, and the bilayer molecular alignment shown in Figure 2 is obtained. A multiple bilayer structure is then formed as the dipping of the substrate into the aqueous suspension is repeated.[1] These structures can provide significant normal incidence reflection only at a set of discretely spaced soft x-ray wavelengths corresponding to the discrete set of fatty acid molecular chain lengths. Furthermore, the low concentration of heavy ions in the metallic salts of fatty acids implies that a large number of layers must be used to achieve good reflectivity. This increase in the number of required layers causes an accompanying increase in absorption, reducing the reflectivity finally obtained.

In the structure described in Figure 1, the wavelength of peak reflectivity has been shifted away from any of the discrete values that a mirror made from a single fatty acid molecule would be restricted to; this has been accomplished by periodically inserting into the structure layers formed from a second species of fatty acid. Increased spacings between the metallic layers can be obtained by transferring some of the fatty acid films from an aqueous substrate not containing metallic ions. The effective period thickness of the structure then becomes approximately the arithmetic mean of all spacing distances in the structure's physical repeat period. Since good performance is obtained from such structures over a small but finite range of wavelengths, a limited set of molecular combinations can provide high reflectance over all wavelenghts in the 70Å-300Å range. (The upper limit simply represents the approximate short wavelength cutoff of conventional reflectors.)

The reflectance of such structures is further enhanced if an additional thin metallic layer is deposited on each monatomic metallic layer that is deposited with the Langmuir-Blodgett technique. This increases the interaction of each individual period with the x-rays, allowing the use of fewer periods in the mirror and consequently the production of mirrors having reduced absorption. If additional metallic layers are used, the resonant wavelength of the mirror can be controlled through variation of the thickness of these layers; rather than through the use of fatty acids having non-uniform molecular lengths.

Present x-ray technology can provide significant reflection of x-rays only at grazing angles of incidence. Recent experimental investigation into the production of x-ray amplifying media suggests that successful fabrication of normal incidence mirrors of moderate reflectivity might make possible the development of x-ray lasers (Figure 3).[2]

The development of normal incidence x-ray reflecting optics would also be of importance in x-ray microscopy and astronomy, in that it would allow better flux collection, larger fields of view, smaller aberrations and finer diffraction limits than grazing optics. There is some indication that a single Langmuir-Blodgett monolayer is capable of bridging small gaps in an underlying substrate, and a cumulative smoothing may be present when multiple layers are deposited. The control over surface roughness that such a smoothing effect might provide would help increase the resolution of x-ray optical systems and would be of interest in other applications.

The development of normal incidence x-ray reflecting optics would also be of benefit in the study of surfaces and in x-ray lithography.

1. G. L. Gaines, Jr., Insoluble Monolayers at Liquid-Gas Interfaces, Interscience, 1966.

2. V. A. Bhagavatula, B. Yaakobi, Opt. Comm., 24, 3, March 1978, p. 331.

Physical Repeat Period of New Type of X-Ray Mirror

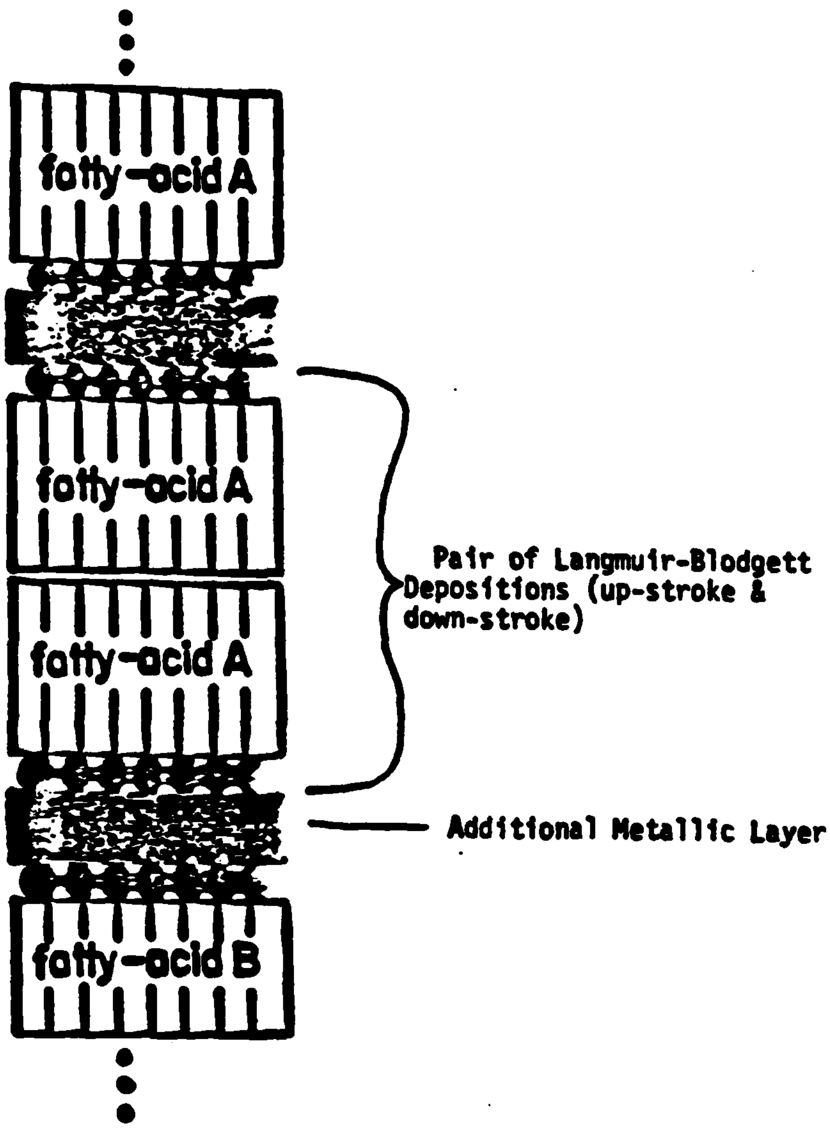

Figure 1

Langmuir-Blodgett Multilayer

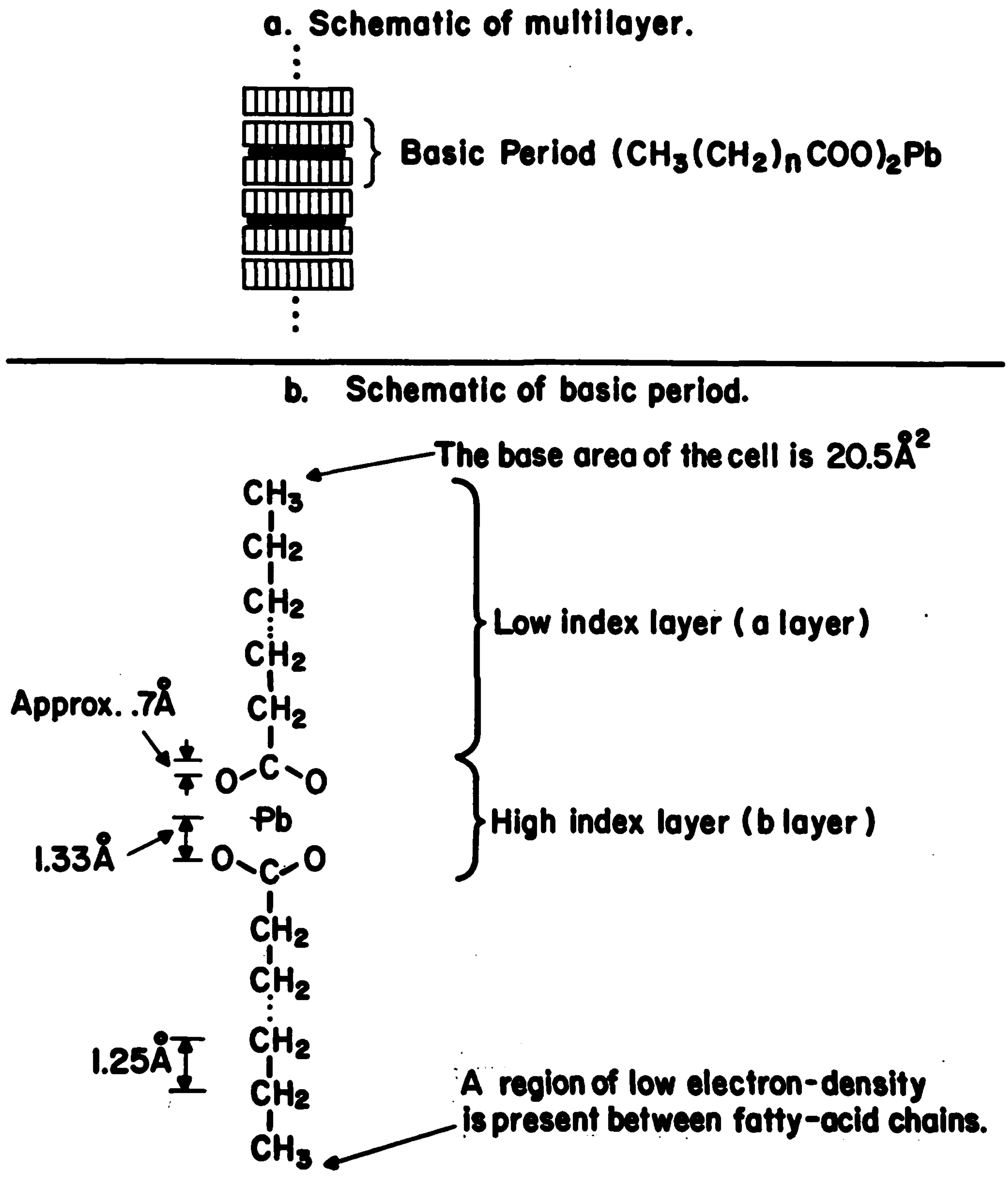

Figure 2

Schematic of Possible X-Ray Laser System

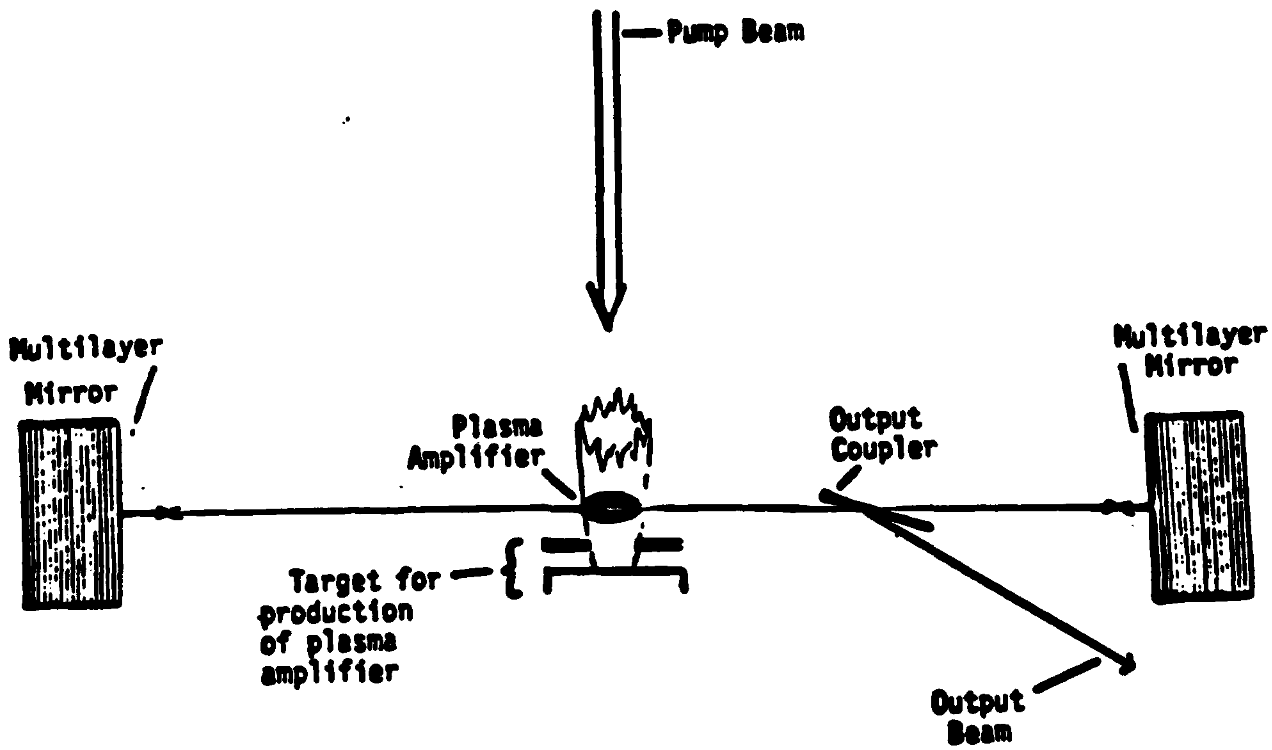

Figure 3

ACKNOWLEDGEMENT

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